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PULSATING GROWTH OF SMALL CUMULI OBSERVED WITH A 95 GHZ AIRBORNE DOPPLER RADAR

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1. INTRODUCTION

The clouds described herein were observed during the Small Cumulus Microphysics Study (SCMS) in east-central Florida, summer 1995. In this paper we examine the evolution of small cumuli as observed by two radars, one of which is a 95 GHz high resolution airborne radar. This is the first report of the use of the airborne radar in the observation of cumulus clouds.

2. DATA

The NCAR CP-2 ground-based dual wavelength radar (Bringi and Hendry, 1990) was used to monitor the overall evolution of the clouds. Clouds chosen for study were within 10 to 20 km of CP-2 which results in a minimum detectable signal of -30 to -25 dBZ_e. Reflectivities reported in this paper from CP-2 correspond to measurements made in the X-band.

Microphysical measurements were made by the University of Wyoming King Air aircraft which is equipped to measure thermodynamic parameters, air motion, and hydrometeor size distributions. Size distributions for particle diameters ranging from 2 to 200 microns were reconstructed from measurements made by the PMS FSSP and the PMS 1D-C. The 95 GHz airborne radar (Kestrel) is also mounted on the King Air. This radar provides high-resolution cross sections from a beam which can be oriented either upward or sideways, normal to the flight path of the aircraft. Nominal resolution is about 15 m along the flight path (at 1 km) and 30 m along the beam.

Doppler velocities retrieved from Kestrel have been corrected for aircraft motion. In this work we refer to these ground-relative Doppler velocities for the vertical beam as 'vertical air velocities' since the contribution due to droplet terminal fall speed is negligible.

Reflectivities reported from CP-2 are generally about 5 to 15 dB higher than those measured by Kestrel. For one of the days studied (Aug07) differences are about 10 to 15 dB, while on the other day (Aug05) differences are 5 to 10 dB. The two most likely sources for this discrepancy are from mis-calibration of either one or both radars and contribution of signal due to Bragg scattering (Knight and Miller, 1993) in the X-band reflectivities.

Reflectivities from CP-2 were plotted as time-height cross-sections for a given cloud. The temporal resolution for plots of this type are about 2.5 minutes (the time required to complete one scan). From these plots it is evident that the clouds studied experience more than one pulse of vertical growth. These pulses are defined by picking a given contour (-10 dBZ_e) and looking for substantial increases in height of the top of this contour. Corresponding growth rates for these echoes are calculated based on the slopes of these contours. The pulses are split into stages based on the development of the echo observed by both CP-2 and Kestrel (growth period: first few minutes of rapid growth; maximum depth: time near maximum height of -10 dBZ_e echo; and decay: time after active growth of the echo with possible decrease in echo top height).

3. OBSERVATIONS

The data described herein were collected on two days during SCMS (Aug05 and Aug07). First, we describe separately the general atmospheric conditions and the evolution of the clouds on these days. Then we discuss similarities and differences between the cloud evolution and attempt to formulate some generalizations concerning the evolution of these clouds.

3.1 *Aug05 Cases*

The lowest 1.3 km of the atmosphere on Aug05 was relatively moist (dewpoint depression of 3.5 °C) and characterized by a nearly adiabatic lapse rate (8 °C km^{-1}). A weak subsidence inversion manifested as an isothermal layer with significant drying (dewpoint depression of ~15 °C) was located between 1.7 and 2.0 km. This inversion acted to suppress convection.

Clouds formed with bases at 800 m and tops extended to 3 km. The King Air made several passes (3 to 6) through a number of clouds at different stages of their growth. All of the penetrations were made at 1.5 km with the airborne radar in uplooking mode. Maximum cloud liquid water contents observed by the King Air were between 1.5 and 2.0 g m^{-3}. Droplet concentrations of 300 cm^{-3} were observed. Maximum radar observed vertical velocities (from Kestrel) were about 9 m s^{-1} and occurred at all levels at or above the King Air. Maximum reflectivities observed by Kestrel were about -5 dBZ_e and about 2 dBZ_e for CP-2. Only one cloud was observed to produce drizzle out of its base, this was confirmed by reports from aircraft flying at mid-levels (King Air) and cloud base (NCAR C130).

All of the clouds sampled on Aug05 were observed to exhibit a pulsating behavior of growth. Overall cloud lifetimes were about 30 minutes during which time 2 to 3 pulses of vertical growth were encountered. The growth period of each pulse lasted about 10 minutes. These periods of growth were separated by about 5 minutes during which time there was only slight decay.

The initial formation of the -10 dBZ_e echo (CP-2) occurred at 1.5 km. Data from Kestrel indicate that the largest reflectivities of a pulse were located in center of the cloud, co-located with the strongest updrafts. The rates of increase in height of the -10 dBZ_e echoes were between 1.5 and 3.0 m s^{-1}. This is slightly larger than the mean vertical velocities of 1 m s^{-1}, but smaller than the 90th percentile vertical velocities of 4 to 5 m s^{-1}. Growth rates for -10 dBZ_e echoes were considerably less for later pulses, primarily because there was little decay of these echoes between pulses.

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The -5 dBZ_e echoes (again CP-2) formed at about 2.0 km generally during the growth periods of second pulses (but in one case during the maximum depth phase of the first pulse). The rates of growth for these echoes were about the same as those for the -10 dBZ_e echoes for the same cloud.

A few of the clouds produced echoes greater than 0 dBZ_e. These echoes formed at 2.0 km, within 300 m of the -20 dBZ_e echo top during maximum depth stage for the final pulse.

Droplet spectra at 1.5 km for all of the clouds observed were bi-modal with peaks at about 8 and 22 microns. A sharp roll off in the concentration occurred around 25 microns. Beyond this size, a tail with drops as large as 200 microns existed with concentrations initially 6 orders of magnitude (~5 orders of magnitude in later stages) less than those of the cloud droplets. The cloud droplet spectra did not change significantly from pulse to pulse, but the concentration of larger droplets increased as did the reflectivity throughout the lifetime of the cloud.

3.1 Aug07 Cases

Atmospheric soundings indicate that the lowest 1.3 km of the atmosphere on Aug07 was very similar to that on Aug05. These soundings also indicate a subsidence inversion located between 1.3 and 1.5 km. Within this inversion temperature increased 1.5 °C over 200 m and the dewpoint depression was about 25 °C.

The King Air penetrated a number of clouds at various stages of their growth. Altitudes of penetrations ranged from 1.3 to 1.8 km. Each cloud was sampled between 4 and 6 times. During each penetration Kestrel was in uplooking mode.

General cloud characteristics were similar to those examined from Aug05. Cloud bases, cloud tops, cloud liquid water contents, and maximum updrafts were all comparable to the observations from Aug05. However, maximum droplet concentrations of 600 cm^{-3} were sampled at mid-levels in these clouds, twice as high as those sampled in clouds on Aug05. This increase in droplet concentration was associated with surface winds which were westerly (offshore) resulting in a CCN spectra which was slightly more continental.

The -10 dBZ_e echoes (CP-2) initially formed early in the first pulse of these clouds at 1.6 km. The decay between pulses was greater for these clouds owing to the drier and more stable inversion layer. In many of the cases, the -10 dBZ_e echo completely vanished between pulses. The growth rate of the -10 dBZ_e echo was 1.5 to 2.0 m s^{-1}. Although the observed growth rates were slightly less than those observed from the Aug05 cases, the mean and maximum vertical velocities were quite similar. The growth rates of these echoes in subsequent pulses were quite similar to those observed in the first pulse of the clouds. A -5 dBZ_e echo was observed to form in nearly all pulses at a level of about 2.0 km. These echoes formed at a time in which the pulse of growth was reaching maximum depth and the echoes quickly decayed as the pulse began to collapse.

Droplet spectra at 1.3 km were bi-modal with peaks at 6 microns and at 18 microns. A sharp roll off in the spectrum occurred at 20 microns, *i.e.*, at a smaller size than observed in the Aug05 data. Again, a tail was observed to extend to 200 microns where concentrations were 6 to 6.5 orders of magnitude less than FSSP droplet concentrations.

4. DISCUSSION

In general, the growth of the observed cumuli occurred in pulses which lasted about 10 minutes. The growth of the pulses acted almost as bubbles rising up through the atmosphere. Early in the growth period of a pulse the vertical velocities through the depth of the cloud are upward, with maximum velocities located in the horizontal center of the cloud. It is at this location where the maximum radar reflectivity forms. As the pulse progresses, the maximum vertical velocity is found near cloud top, with maximum reflectivities again located in the updraft but outside of the region of maximum vertical velocities. As the pulse reaches maximum depth, the largest reflectivities are found near the top of the cloud. Subsequent entrainment of drier, denser air acts to suppress any further vertical growth. At this point the cloud will begin to decay until it disappears or another pulse reinvigorates growth.

The amount of decay between pulses for the cases examined is well correlated with the strength of the inversion and the moisture content of the environmental air within and above the inversion. As was the case with clouds on Aug07, a stronger inversion and drier air lead to much more decay between pulses. Because of this, pulses from clouds on Aug07 appear to be almost separate entities. Droplet spectra change systematically during the growth period with each pulse following the same pattern. Conversely, for clouds on Aug05, subsequent pulses are generally stronger with concentrations of larger droplets and reflectivities increasing throughout a cloud's lifetime. Because of this, clouds on Aug05 achieved larger reflectivities and eventually larger concentrations of drizzle drops than those clouds observed on Aug07.

A great puzzle in these data is that clouds with similar cloud base conditions of temperature and moisture content achieved reflectivities of -10 and -5 dBZ_e at nearly the same level even though the droplet spectra were different on these two days. Complicating this problem is the mis-match in reflectivities from the two radars. Because of this, a quantitative comparison of measurements between the two radars needs to be addressed to determine if this difference in reflectivities is due to actual backscatter differences (possibly including Bragg Scattering) or due to mis-calibration of the radars.

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5. References

Bringi, V. N., and A. Hendry, 1990: Technology of polarization diversity radars for meteorology. In *Radar in Meteorology*. D Atlas, editor; AMS, Boston, 153-190.

Knight, C. A., and L. J. Miller, 1993: First radar echoes from cumulus clouds. *Bull. Am. Meteorol. Soc.,* **74**, 179-188.